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THE EMI-SUSCEPTIBILITY EVALUATION OF THE MARK 45 MOD 0 GUN MOUN--ETC(U)

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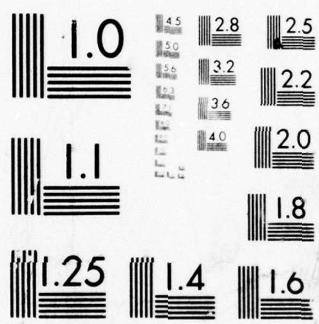
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THE EMI-SUSCEPTIBILITY EVALUATION OF THE MARK 45 MOD 0 GUN MOUNT

July 1972

Prepared for
NAVAL ORDNANCE STATION, LOUISVILLE (NAVORDSTALOU)
LOUISVILLE, KENTUCKY
under Contract N00197-71-C-0222
Modification to Specific Task Assignment Number 3

ARINC RESEARCH CORPORATION

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Prepared for
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ABSTRACT

The electronic circuits of the Mark 45 Mod O 5"/54 Caliber Gun Mount were reviewed to determine the potential impact of EMI effects. This review took into consideration known power levels of certain transmitting equipments and included detailed analysis of the individual gun-mount control circuitry. On the basis of the findings, future testing approaches are recommended.

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1. INTRODUCTION

This report summarizes the findings of an engineering investigation of potential effects of EMI on the operation of the Mark 45 Mod O 5"/54 Caliber Gun Mount. This investigation was conducted for the Naval Ordnance Station, Louisville, under a modification to Specific Task Assignment Number 3 of Contract N00197-71-C-0222.

The electronic system of the Mark 45 Mod O Gun Mount was studied to identify where Electromagnetic Interference (EMI) effects would be most likely to occur and what effect they would have on the operation of the gun mount. Since the only electro-explosive devices (EEDs) present in the system are in the ammunition, and since HERO testing has been conducted separately on the ammunition, the study concentrated on possible gun-mount malfunctions due to EMI effects on logic-control circuitry and gun-laying (train and elevation) circuitry. It was found that two basic types of malfunctions could occur. The first is a logic error in the sequencing control circuitry, in which the EMI effect would be a false indication that one or more events had occurred. The second type is a gun-laying error, in which the EMI effect is a displacement of the null in the synchro receiver.

2. TECHNICAL DISCUSSION

The logic circuits identified as being the most susceptible to EMI are the buffer circuits associated with mechanical switches, relays, and photo cells (Figure 1). The first electronic element in the input to buffer circuits is a diode that will rectify any EMI picked up by the leads from the sensor (switch, relay, or photocell) to the buffer. The rectified energy will charge the 6-microfarad capacitor. If the charge on the capacitor exceeds approximately 0.7 volt, the buffer will switch logic states and will falsely indicate that the event being monitored has occurred. The inverter buffer circuits (Figure 2), associated with the Hall-effect proximity switches, are not similarly sensitive to EMI, because the 100-ohm resistor and 0.22-microfarad capacitor that precede the diode constitute a low-pass filter. However, the Hall-effect switches themselves, if inadequately shielded, are susceptible to EMI effects that would cause false indications.

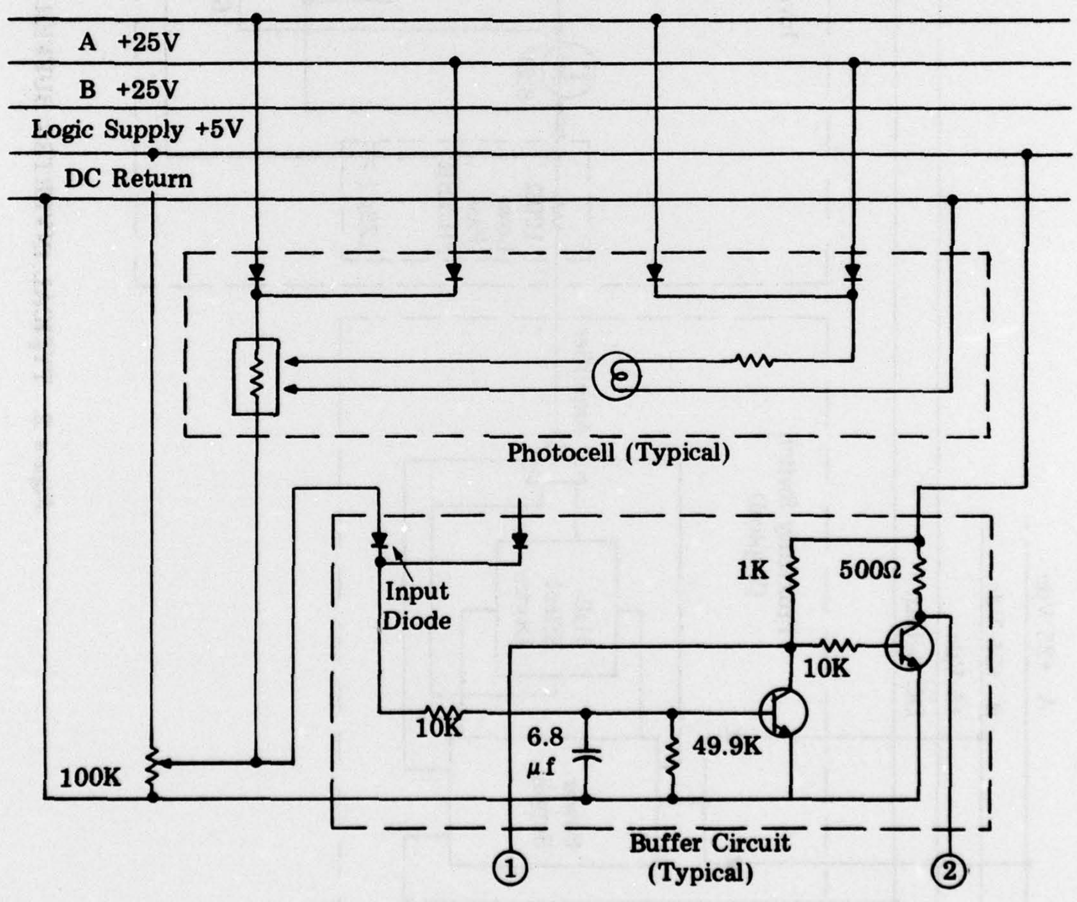

Figure 1. **TYPICAL BUFFER-CIRCUIT INPUT**

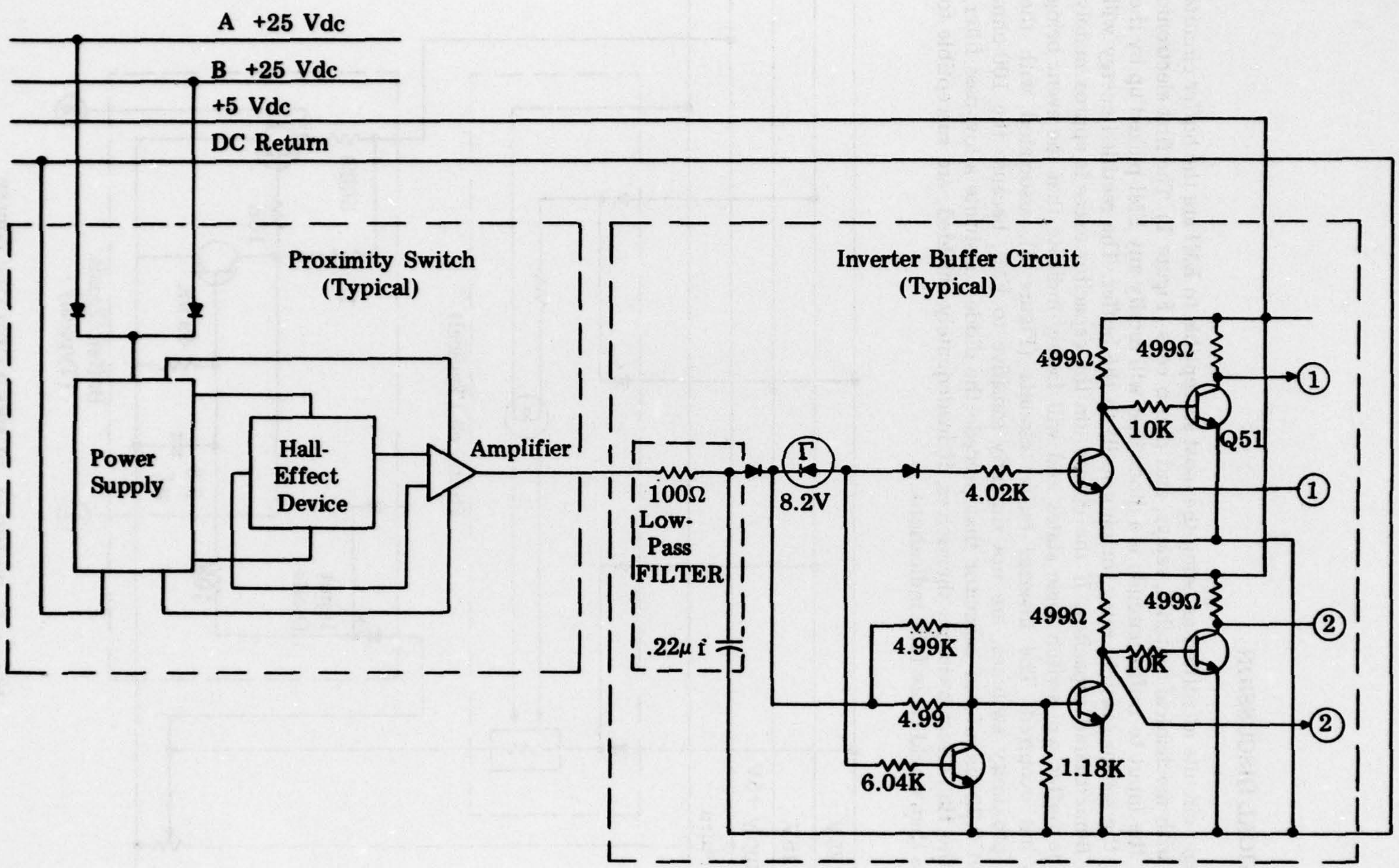

Figure 2. **TYPICAL INVERTER BUFFER CIRCUIT**

2.1 Effects of False Indications

False event indications can have three possible effects. They can cause a subcycle to be initiated out of sequence, cause a subcycle in progress to be interrupted, or have no effect that is apparent to the operators.

In the first case, if all but one of the logic states required to initiate a subcycle exist, a false indication can erroneously create the remaining logic state and cause the subcycle to be initiated in improper sequence. Because extensive interlocks are designed into the system, only rarely will a catastrophic failure or hazardous condition result from a false event indication. Identification of all possible out-of-sequence subcycle initiations was beyond the scope of this study; however, it was noted that a false indication from the safe-firing-zone switches could permit the gun to be fired in an unsafe firing zone.

The second case involves a latching circuit (Figure 3). The figure is simplified but is typical of latching circuits. The output of AND gate 1 is the culmination of a complex logic chain and is one of three inputs to AND gate 2. Each of the other two inputs to AND gate 2 is the culmination of a logic chain. When the three inputs to AND gate 2 are present, the output from the gate signals for a solenoid to be energized to initiate a subcycle. When the subcycle starts, at least one of the inputs to AND gate 1 will disappear and the subcycle will stop. Therefore, the OR gate was inserted and the output of AND gate 2 was fed back as an input to the OR gate. Thus when the output from AND gate 1 disappears, the feedback signal from AND gate 2 substitutes for it and latches AND gate 2 until the subcycle is completed.

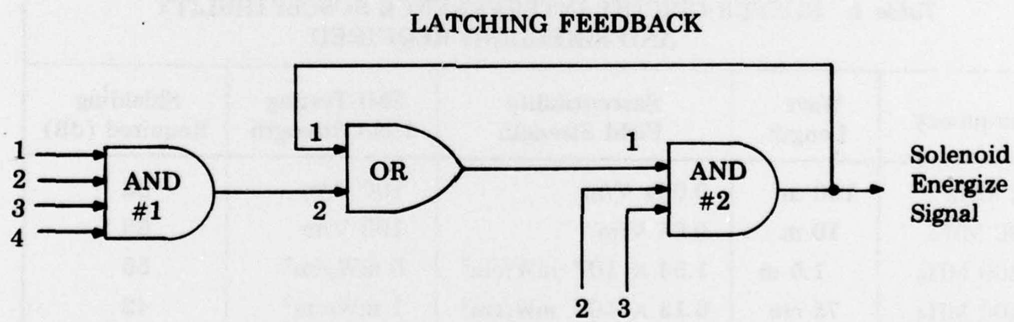

Figure 3. **LATCHING CIRCUIT**

When the subcycle is completed, one or more of the inputs to the other logic chains into AND gate 2 will disappear and the output from AND gate 2 will disappear, thus de-energizing the solenoid. When the output from AND gate 2 disappears, the latching circuit is also released. While the subcycle is in progress, if a temporary EMI effect causes input 2 or 3 to AND gate 2 to disappear, the output from the gate will disappear, thus de-energizing the solenoid and releasing the latch. When the interference effect ends, the

interrupted input to AND gate 2 will be restored, but since the starting of the subcycle routinely interrupted one or more of the inputs to AND gate 1 and the latching feedback has dropped out, there is no input 1 to AND gate 2. Thus, the subcycle stays interrupted and can be restored only by analysis of the interruption and manual intervention. It is possible that an as yet undiscovered logic design fault could then permit the next subcycle to be initiated, thus creating a catastrophic failure or a hazardous condition. It would require an exhaustive analysis of the logic circuitry and hydraulic system to identify such a logic design fault.

In the third case, a false indication can remain undetected for as long as the subcycle(s) with which it is associated remains idle. If the false indication is temporary or intermittent, it will be undetected if its existence does not coincide with an operating period of the subcycle(s) with which it is associated. Thus it will be possible for frequent intermittent false indications to occur without any malfunctions being apparent to the operators.

2.2 EMI Sensitivities

The field strengths at which EMI effects would occur in the buffer circuits were calculated as shown in the appendix to this report. In making the calculations, it was assumed that the signal leads to the buffer input were resonant at the frequency of the EMI field and that the leads were unshielded. The field strengths at which EMI effects would occur are shown in Table 1. The table also shows the frequency, the wave lengths, the field

Table 1. **BUFFER-CIRCUIT INTERFERENCE SUSCEPTIBILITY AND SHIELDING REQUIRED**

Frequency	Wave Length	Susceptibility Field Strength	EMI-Testing Field Strength	Shielding Required (dB)
2 MHz	100 m	0.004 V/m	100 V/m	88
30 MHz	10 m	0.04 V/m	100 V/m	68
200 MHz	1.5 m	1.54×10^{-5} mW/cm^2	5 mW/cm^2	55
400 MHz	75 cm	6.15×10^{-5} mW/cm^2	1 mW/cm^2	42
1 GHz	30 cm	1.71×10^{-4} mW/cm^2	1 mW/cm^2	38
3 GHz	10 cm	3.46×10^{-4} mW/cm^2	100 mW/cm^2	55
6 GHz	5 cm	1.38×10^{-3} mW/cm^2	100 mW/cm^2	49
10 GHz	3 cm	3.84×10^{-3} mW/cm^2	100 mW/cm^2	44

strength to be used to test for EMI susceptibility, and the shielding of the leads required to prevent EMI effects at the testing field strength. Safety margins are incorporated in the EMI-testing field strengths; therefore, the indicated shielding will have an adequate safety margin in the actual operating environment.

2.3 EMI in Gun-Laying Circuits

EMI effects in the gun-laying circuitry can be caused by the interference of radio frequency fields with the operation of the servo amplifiers. However, interference effects are more likely to occur from stray coupling to the 400-Hz power-supply leads. Therefore, no attempt was made to calculate susceptibility levels for the pointing circuitry. A technique for testing for EMI effects in the pointing circuitry will be suggested in Section 3.

2.4 Field Strengths for EMI Testing

The electromagnetic-environment levels to which shipboard equipments are subjected have not increased appreciably in the past 10 years in the frequency ranges up to 1.5 GHz and are not expected to increase significantly in the foreseeable future. In the 3-GHz to 10-GHz radar frequencies the increases have been substantial, and there are indications that the trend will continue. The field-strength levels at which the gun mount was HERO-tested are adequate for all frequencies except the 3-GHz frequency. It is recommended that the EMI testing be conducted at 100 mW/cm^2, as shown in Table 1, to provide a safety margin against power-generating systems now under development. Although the shielding requirement shown in Table 1 is not difficult to achieve, it must be borne in mind that at radar frequencies any deterioration in the shielding — such as may occur around access doors or ventilation ports — very sharply decreases the effectiveness of the shielding and permits significant energy levels to penetrate the enclosure.

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3. RECOMMENDED TESTING METHOD

Since the only EEDs present in the gun mount are in the ammunition, which has been tested separately, it is recommended that the testing be patterned after EMI procedures rather than HERO procedures.

The previously discussed possibility that false indications will occur without being apparent to the operator makes it questionable whether EMI effects will be detected by exercising the gun mount while it is illuminated by electromagnetic energy. False indications could be identified by using the logic status board in the EP-2 operator's panel; however, the rear door of the panel must be open, and this substantially reduces the shielding provided for the logic boards by the panel structure.

The suggested method of testing is to laboratory-test the logic boards, buffers, and inverter buffers for EMI-sensitivity level. The tests should be conducted with the circuits unshielded and with representative lead lengths and configurations. Then the complete gun mount should be tested by testing for field strengths inside the weather shield and the operator panels and for EMI pickup on cabling under various angles of illumination and with various gun-mount configurations. If the interior field strengths and EMI pickup on cables are at least 6 dB below the laboratory-measured sensitivity levels, then there are no EMI problems in the sequencing-control-logic circuits due to radio-frequency transmitters.

A separate engineering program is being conducted by the manufacturer to raise the EMI resistance of the Hall-effect proximity switches. However, it is recommended that these switches be included in the laboratory testing to confirm their resistance to EMI effects.

The gun-laying circuitry is analog and can be tested in the normal manner for EMI effects. The maximum tolerable pointing error in azimuth and elevation should be calculated. The mount should be pointed at selected azimuth and elevation angles, and the differences in the angles with and without illumination should be measured and compared with the calculated maximum tolerances.

Because of the trend toward installing more electrically powered equipment and toward increased power consumption in such equipment, the power lines could constitute a major source of electromagnetic interference through switching transients and EMI pickup. Therefore, it is recommended that appropriate tests be carried out for conducted interference. Tests of the gun mount as a source of interference should be performed, as well as tests of the gun mount for susceptibility to interference.

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APPENDIX

EMI CALCULATIONS FOR BUFFER CIRCUIT

Figure A—1 shows the buffer circuit, including the lead-in wire assumed to comprise the virtual antenna by which EMI signals can couple to the circuit. For computational purposes, the signal leads to the buffer circuit are assumed to be capable of being represented by a

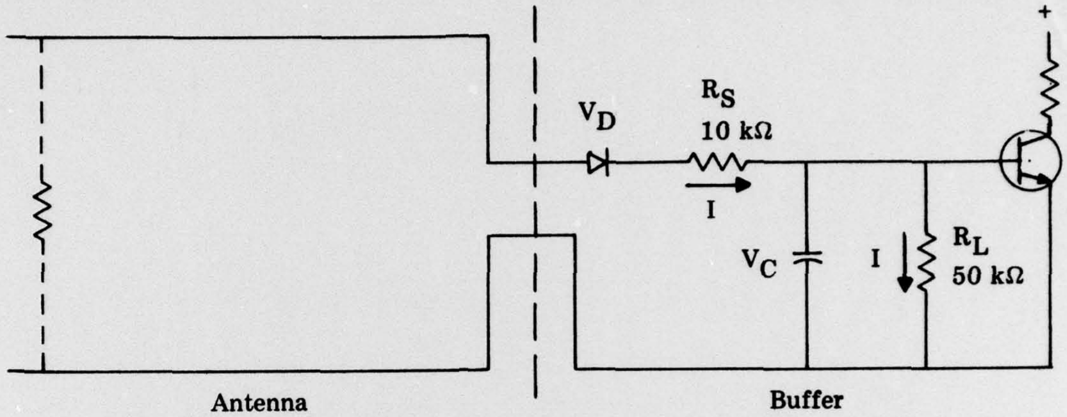

Figure A—1. **BUFFER CIRCUIT, INCLUDING LEAD-IN WIRES**

one-half-wave dipole antenna (a worst-case assumption) at the frequency of the interfering signals. Other assumptions used in the computations are as follows:

V_C = 0.7 V (the voltage required to turn on the transistor)

V_D = 0.7 V (the voltage drop across the silicon diode)

The expression for the power consumed in R_L is given by

$$P_{R_L} = \frac{\left(V_{R_L}\right)^2}{R_L} = \frac{\left(V_C\right)^2}{R_L} = \frac{(0.7)^2}{50K} = 0.0098 \text{ mW}$$

Since the current through R_S is the same as that flowing in R_L, it follows that

$$P_{R_S} = I^2 R_S = \frac{1}{5} P_{R_L} = 0.00196 \text{ mW}$$

Also, since the current through and the voltage across the diode are the same as for R_L, it follows that the power consumed by the diode is the same as that consumed by R_L; thus

$$P_D = I\,V_D = P_{R_L} = 0.0098 \text{ mW}$$

It also follows that the total power consumed in the buffer circuit as the transistor reaches turn-on is given by

$$P_T = P_{R_L} + P_{R_S} + P_D = 0.022 \text{ mW}$$

The total power expended in the buffer circuit can be related to the spatial power density, antenna gain of the virtual antenna, and wavelength of the interfering signal by the equation

$$P_T = \tfrac{1}{2} P_d A_e = \tfrac{1}{2} \frac{E^2}{120\pi} \frac{G\lambda^2}{4\pi}$$

where

P_d = the spatial power density in watts/m^2

$P_d = \dfrac{E^2}{120\pi}$

E = the electric-field intensity

A_e = the effective area of the virtual antenna

$A_e = \dfrac{G\lambda^2}{4\pi}$

G = the antenna gain

λ = the wavelength of the interfering signal

Solving the above equation for the electric-field intensity yields

$$E = \left(\frac{960\pi^2 P_T}{G\lambda^2}\right)^{1/2}$$

This field-intensity level is that level required to induce a 0.7 V level on the base-to-emitter terminal of the transistor shown in Figure A–1. Substituting the value for P_T previously calculated, and the value for the gain of a one-half-wave dipole (1.6 ≡ 2 dB) into the above equation reduces the equation to

$$E = \frac{0.364}{\lambda}$$

In order to account for the possibility of power gain from the input leads to the buffer circuit, it was assumed that the maximum lead length subject to coupling with an external field would be 0.75 meter. It was also assumed that the maximum power gain above that yielded by a one-half-wavelength set of leads would not exceed 10 dB. Thus, for wavelengths less than or equal to 1.5 meters, the input leads to the buffer circuit were assumed to act as a long-wire antenna, thus exhibiting a power gain as shown in Figure A–2. With this assumption taken into account, the electric-field strengths required to produce an EMI-susceptibility level were adjusted by this power gain, yielding

$$E = \left(\frac{0.364}{\lambda}\right)k \quad ; \quad \begin{array}{l} \lambda < 1.5 \text{ meters} \\ f > 200 \text{ MHz} \end{array}$$

where

k = the voltage gain relating to the power gain at the wavelength of interest

= antilog $G_{p/20}$

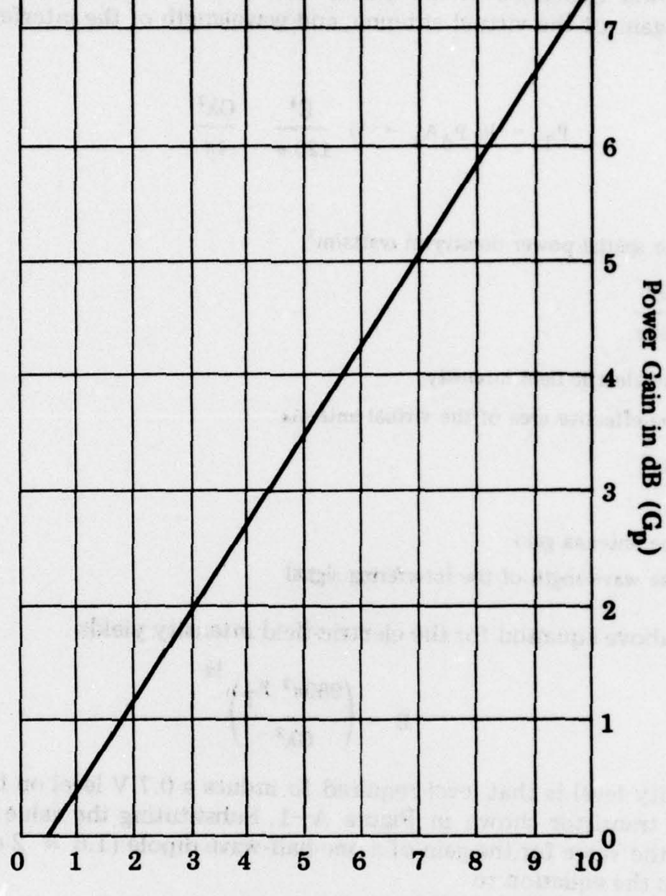

Figure A–2. **POWER GAIN OF A HORIZONTAL LONG-WIRE ANTENNA**

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